SYNOPSIS OF P.G. RESEARCH PROBLEM

ON

SUSTAINABLE VALORIZATION OF BANANA STEM WASTE: DEVELOPMENT, AND OPTIMIZATION OF BIODEGRADABLE PACKAGING SYSTEMS

UNDER THE GUIDANCE OF

Dr. M. N. Dabhi

PROFESSOR AND HEAD

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

JUNAGADH AGRICULTURAL UNIVERSITY

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SUBMITTED BY

SATYAM KUMAR

(Reg. No. 1050225008)

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1.	**Name of Student**	:	Satyam Kumar
2.	**Name of Degree submitted for**	:	Ph.D. (Agril. Engg.)
3.	**Registration Number**	:	1050225008
4.	**Major Subject**	:	Processing and Food Engineering
5.	**Minor Subject**	:	Biochemistry
6.	**Name of Major Advisor**	:	Dr. M. N. Dabhi
7.	**Title of Research Problem**	:	**Sustainable Valorization of Banana Stem Waste: Development, and Optimization of Biodegradable Packaging Systems**

INTRODUCTION

One of the most prevalent plants in tropical and subtropical regions of the world is the banana (Musa paradisiaca). The Malaysia-Indonesian area of South East Asia is home to banana plants, which belong to the Musaceae family. Chafidz (2020). An estimated 840,362 tons of bananas are produced annually in Bangladesh. Every year, a variety of banana species (Genre Musa) are collected, although only the plant's edible fruit is use. The residue is thrown away and is typically regarded as environmental trash. For example, the leaves and pseudo stem of the banana plant are burnt when the plant releases a lot of greenhouse gases into the atmosphere after harvesting banana fruits. (Hasanah *et al.,*2023). Nearly every part of the banana plant is useful; for example, the fruits are nutritious for human health, the peels are use as antioxidants, the leaves are used for wrapping, and the pseudo stems are used to make high-quality, specialized sanitary products like baby pampers. The stalks are use to prevent diabetes. (Sharma *et al.,*2021)

A distinctive characteristic of banana plants is referred to as "banana pseudo stem." The pseudo-stem of a banana, commonly known as the A unique and vital component of the banana plant (Musa species) is the banana stem. It arises from the plant's subterranean corm as a thick, cylindrical structure rather than a genuine stem. (Bilba *et al.,* 2021). Sanitary items including baby diapers, pulp, paper raw materials, textile fiber, and filler or structural reinforcement in composite materials are all made from banana pseudo stems. This fiber is also used to make filter cloths, coffee and tea bags, light-density woven fabrics, plaster reinforcing fibers, and disposable textiles. The pseudo-stem fiber of the banana plant is similar to pineapple leaf, sisal, and other stiff fibers, but it is slightly more elastic. (Kumar *et al.,* 2017)

“The most common chemical in the world and a crucial structural element of plant cell walls, cellulose, is found in banana plant waste. Cellulose is a renewable resource that contributes to its sustainability because it is found in many plants and is made from materials like cotton and wood. Compared to synthetic alternatives, cellulose is more ecologically benign since it is biodegradable and can be broken down by natural processes. Cellulose is useful for industrial uses including paper, textiles, films, and composites because of its strength and stiffness, which are essential for plant structure. (Ibhrahim *et al.,*2023)

Cellulose-based packaging materials offer full biodegradability, biocompatibility, and organic derivation in the food business, making them a viable substitute for environmentally friendly packaging materials based on polyethylene. (Kumar and Mohanraj 2023). Cellulose's remarkable ability as a reinforcing material, favourable mechanical properties, low density, and beneficial environmental benefits have sparked recent research interest in the material, which is pushing applications in the manufacturing of composite materials. Because of its film-forming capabilities, biodegradability, crystallinity, and mechanical qualities, polyvinyl alcohol (PVA), a synthetic, flexible, and biodegradable polymer, is used in the packaging sector. BBS (2021-23)

Sr. No.	**State**	**Area (ha)**	**Production (MT)**	**Productivity (MT/ha)**
1	Tamil Nadu	111.36 (14.35)	5136.20 (19.38)	46.10
2	Gujarat	97.40 (12.55)	4523.49 (17.06)	64.10
3	Maharashtra	92.65 (11.94)	3260.13 (12.28)	43.90
4	Andhra Pradesh	82.00 (10.57)	3449.01 (13.53)	42.00
5	Karnataka	70.58 (9.10)	2529.60 (9.54)	36.00
6	Bihar	51.51 (6.65)	1702.41 (6.42)	51.50
7	M.P.	33.06 (4.26)	1071.00 (4.02)	66.00
8	West Bengal	44.70 (5.76)	1077.80 (4.07)	24.10
9	Assam	27.49 (3.54)	837.02 (3.16)	16.20
10	Odisha	25.76 (3.32)	521.31 (1.97)	19.00
11	Others	139.49 (17.97)	1637.47 (6.17)	11.70
Total	—	**776.00 (100)**	**26509.10 (100)**	**34.20**

The banana plant is mostly grown for its fruit; the other portions are sometimes throw away. Just 12% of the plant's weight is made up of fruit; the rest 88%, which includes the pseudostem, leaves, and male flowers, is thrown in the trash. However, these sections are high in cellulose, hemicellulose, and lignin, and the strength of the fiber varies depending on the portion of the plant. Banana Plant stem was employed as a source of fiber in the thirteenth century, but it was eventually abandoned as crops like cotton and silk were introduced. (Panjwani *et al.,*2023)

Banana Plant stem is an excellent source of total dietary fiber, polyphenols, and flavonoids. It includes cellulose (~31.27%), hemicellulose (~14.98%), and lignin (~15.07%) . Banana leaves, on the other hand, have around 26% cellulose, 17% hemicellulose, and 24% lignin. (Oluwole *et al.,*2022). Pseudostem fibers have tensile properties that are significantly higher than those of fibers from other sections of the banana plant. For example, the tenacity of Pseudostem fibers is 5.3 g/den, whereas the tenacity of banana leaf sheath fibers is 2.4 g/den. Due to its high stiffness and lack of cohesiveness, banana fiber finds few uses in the textile industry. (Nascimento *et al.,*2025)

The two fundamental methods for mechanical extraction are the Bacnis and Leonit procedures. The first step in the Bacnis process is tuxing, which entails either manually or mechanically separating the fiber bundles from the other components. The manual extraction process is retting the pseudostem in water for around 14 to 21 days, then using knives to remove the pulp and degumming. Fibers are extracted by the process of degumming, which involves removing lignocellulosic impurities. However, the manual approach is time-consuming, labour-intensive, requires specialized workers, and requires chemical treatment to slow the rate of water absorption. (Ranjha *et al.,*2022)

The tuxing process results in fiber bundles that are around 5–8 cm wide. To acquire fiber, the tuxy ribbons are plucked, crushed, and the pulpy material is extracted. Using a sharp, pointed instrument, the ribbons are removed from the sheath during the Loenit process. After that, a comb-like instrument is used to separate the fibers. The majority of the mechanical process uses a combination of scraping and retting water. After obtaining the fiber, gum and non-fibrous components are removed, and the fibers are then completely cleaned and dried. (Bhawani *et al.,*2023)

Cellulose, hemicellulose, and lignin make up the majority of the lignocellulosic material found in banana pseudostems, which account for 20–30% of the plant biomass. These

polymers, especially cellulose, which has exceptional film-forming capacity, tensile strength, and biodegradability, are fundamental components in the production of biopolymer films. (Yang, 2015)

Pseudostem-derived cellulose has been effectively used to create biodegradable packaging sheets with mechanical stability and water resistance that are appropriate for food preservation. Furthermore, lignin derived from pseudostems may be used in composite biofilms as a filler or crosslinking agent to improve their antioxidant and UV resistance. Additionally, the biomass's enzymatic hydrolysis can release fermentable sugars that allow for the generation of bioethanol, supporting integrated biorefinery models that promote circular economies (Nguyen and Nguyen, 2021)

Despite being rich in bioactive components that can help create value-added goods like biodegradable biofilms, banana trash, which includes peels, pseudostems, and leaves, is frequently neglected. Since bananas are one of the most popular fruits in the world, the biomass waste they produce presents environmental problems. Research indicates that during processing, around one-third of the fruit is thrown out (Zou et al., 2022)

9. PRACTICAL UTILITY OF THE RESEARCH WORK

The main objective of this project is to create biodegradable banana fiber boxes, trays, and cushioning materials as environmentally friendly substitutes for traditional plastic packaging. These materials are made to be robust, long-lasting, and appropriate for handling, storing, and transportation uses, especially in the food packaging and e-commerce industries that deal with fruits, vegetables, and ready-to-eat meals. The study offers a useful waste management option by using banana stem debris, an agricultural residue that is frequently thrown away or burnt. In line with global sustainability objectives, this conversion promotes a circular bioeconomy and zero-waste strategy while drastically lowering carbon emissions and environmental pollutants.

By converting low-value banana stem waste into high-value biodegradable goods, this research opens up new business options. By providing banana stems, farmers may make more money, which raises the total profitability of banana farming. By stimulating the development of small-scale fiber extraction facilities and biodegradable packaging enterprises in rural regions, the research also supports rural entrepreneurship. This increases the agrarian economy and promotes decentralized industry growth in addition to improving livelihood prospects.

The design and development of effective technology and processing techniques for turning banana stem Fibers into biodegradable packaging materials is one of the study's main objectives. To increase output, product quality, and operating efficiency, sophisticated fiber extraction techniques and pulp moulding or thermoforming machinery are being developed. In order to ensure that the produced technologies may be commercially utilized, the study places a strong emphasis on scalability and industrial application. Furthermore, the work presents a significant opportunity for innovation and patentable developments in biodegradable processing and packaging equipment .

The work makes a substantial contribution to material science by assessing and enhancing the characteristics of biodegradable packaging made of banana fiber. Important factors including water resistance, mechanical strength, and barrier qualities are carefully examined to guarantee usefulness and longevity under different circumstances. Additionally, the study investigates the creation of bio-composites using natural coatings and binders to improve performance. Applications in the food sector are also looked at, such as takeout containers, dry food packaging, and fresh produce packaging, with a special emphasis on food safety enhancements and antimicrobial characteristics.

The creation of eco-friendly packaging companies and novel product lines based on banana fiber materials is made possible by this study, which has significant commercial potential. In order to promote sustainable packaging options, it makes cooperation with the packaging industry, retailers, and export sectors easier. Furthermore, by offering biodegradable substitutes and assisting in the creation of quality standards and legal frameworks, the study aids government initiatives meant to decrease plastic waste. By providing chances for excellent publications, patents, and technology transfer from academia to industry, the discoveries help promote academic research and close the gap between study and practical application.

10. Research Objectives

1. To develop an efficient extraction and processing methodology for converting banana stem waste into high-quality fiber suitable for biodegradable packaging applications.
2. To develop the biodegradable packaging system utilizing banana stem fibres
3. To optimization of process parameters to enhance the strength of the developed packaging material.

4. To evaluate the storage performance of the developed biodegradable packaging under different storage conditions.

11. Review of Literature

Alzate Acevedo *et al.* (2021), one popular technique for separating biopolymers from banana plant waste is chemical extraction. This method entails using chemicals like sodium hydroxide to dissolve the plant material's intricate lignocellulosic structure. To achieve the required biopolymers, the procedure typically consists of consecutive phases such pretreatment, extraction, purification, and drying. The authors emphasized that, when compared to other traditional techniques, chemical extraction is very successful in obtaining greater yields and enhanced purity of biopolymers.

Alzate Acevedo *et al.,* (2021), mechanical extraction is an easy and affordable way to extract biopolymers from banana plant waste. This method breaks down the plant material and releases its fiber components by using physical pressures like grinding or milling. According to the authors, cellulose fibers from banana trees are frequently extracted mechanically and then processed into biodegradable packaging materials.

Pongsuwan *et al.,* (2022), enzymatic extraction is a sustainable technique for separating biopolymers from plant sources. This method makes use of enzymes like cellulase, which function as biological catalysts to break down certain lignocellulosic structural constituents. High-quality biopolymers may be extracted with little harm to the fiber structure thanks to this selective breakdown, the authors said. Furthermore, because enzymatic extraction uses less chemicals and has a smaller environmental effect than standard chemical processes, it is thought to be more environmentally sustainable.

Solomon *et al.,*(2017) The machine's main parts are a spinning roller, a stationary roller, a feeding gear mechanism, motors, and a belt that transfers motion and torque. The frame supports the entire system. However, the problem of knot formation and fiber breakage in current machines surpasses our hypothetical machine design. Pigments, broken fibers, cellulose coatings, and other impurities were manually removed from the rolled fibers using a comb. The resulting fibers are not uniform, there is more fiber waste, the machine is more expensive, there is less production, the quality of the fiber is poor, it takes more time, and the main disadvantage of these types of existing machines is that complete psedostem should not be used to extract fiber; instead, thin slices of psedostem must be separated before extraction, which requires more labour.

Baek *et al.,* (2019) analysed the box using four distinct package designs, including three grades of corrugated fibreboard and three vent hole regions. The authors found that the corrugated fiberboard grade and the package's compression strength were positively correlated, whereas the vent area and package strength were negatively correlated.

Shirzad and Joodaky (2023) investigated the buckling loads of thin elastic plates with a circular cut-out, varying diameters, and different positions using FEM and experimental experiments. The material's complicated composite structure, anisotropic behaviour, and humidity-dependent characteristics make it difficult to simulate VCP packages using FEM. Errors and decreased accuracy might result from the assumptions made by FEM, such as ideal bonding quality and certain material qualities. Even while sophisticated FEM software can somewhat accurately simulate these structures, the computing requirements make it unfeasible for routine industrial application, especially given the substantial effects of environmental factors like humidity on paper materials.

Razza and Innocenti (2012) demonstrated how biodegradable wet food packaging may improve the quality of composts and the rate at which food waste composts. However, in the particular instance of old dry packaging made of biodegradable plastic, the environmental effects of various disposal solutions must be investigated.

Bishop *et al.,* (2021) used a consequential method to evaluate the environmental effects of replacing petrochemical-based packaging for fruit and vegetables in the UK with PLA. The study examined eight distinct waste management scenarios for PLA packaging, excluding the manufacturing and consumption phase of fruits and vegetables. The findings showed that the creation of PLA packaging had more environmental effects than those of petrochemical plastic, but if PLA packaging and vegetable waste were utilized as feedstock for anaerobic digestion and possible insect feed in the future.

Srivastava *et al.* (2024*)* looked into adding nanocellulose filler, or microcrystalline cellulose. The results showed that the films' mechanical strength and water barrier properties were greatly enhanced by the addition of nanocellulose. Tensile strength increased by 14.3% in films reinforced with 3 weight percent nanocellulose, showing better structural integrity. Furthermore, a 29.7% increase in water vapor permeability indicates improved resistance to moisture transfer. The films' water swelling behaviour also shown encouraging outcomes, with a meager 16.8% weight gain following a 24-hour immersion in water.

12. Material and Method

12.1 Plan of work

1. Raw Material Collection and Preparation
2. Fiber Extraction Process Development
3. Optimization of Fiber Extraction Parameters
4. Pulp Preparation from Extracted Fibers.
5. Incorporation of Natural Binders/Additives
6. Development of Biodegradable Packaging Materials
7. Characterization of Developed Materials
8. Process Optimization Using Statistical Tools
9. Biodegradability and Environmental Impact Assessment
10. Prototype Development and Performance Testing
11. Economic Feasibility and Scale-up Analysis
12. Documentation and Thesis Preparation

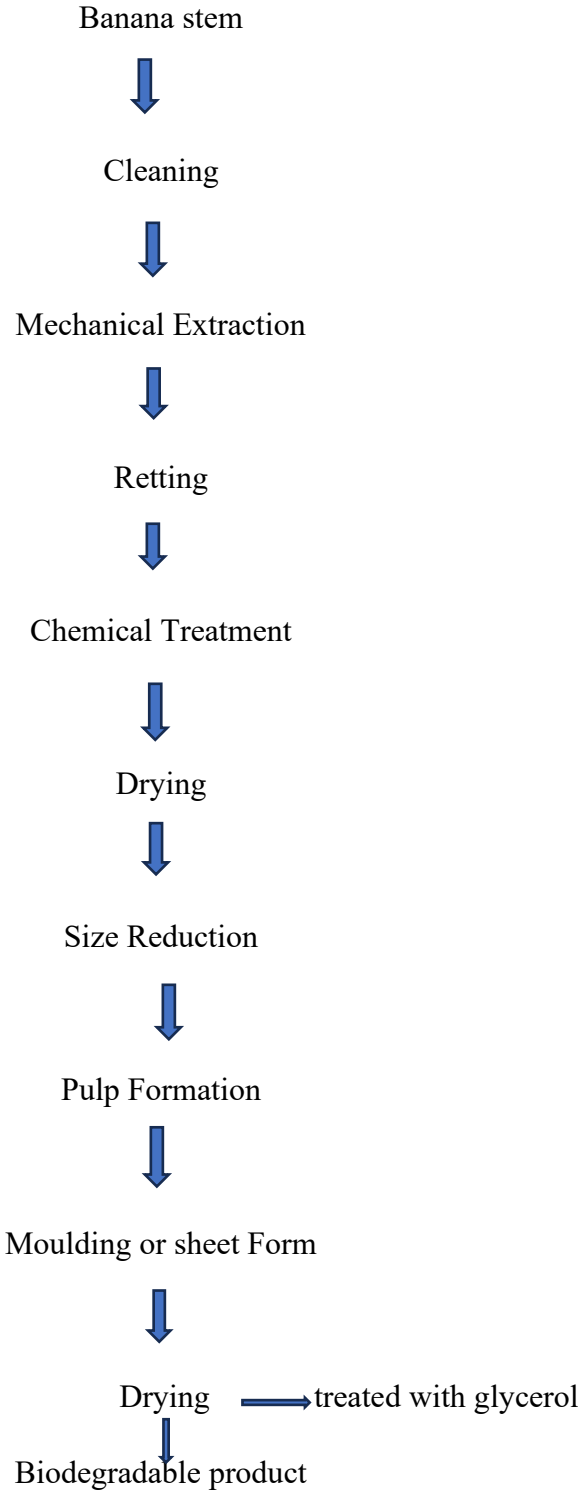
12.2 Experimental details

i.	**Location**	:	Department of Processing & Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh
ii.	**Crop**	:	Banana (Musa paradisiaca)
iii.	**Year and season of experiment**	:	2026-2027

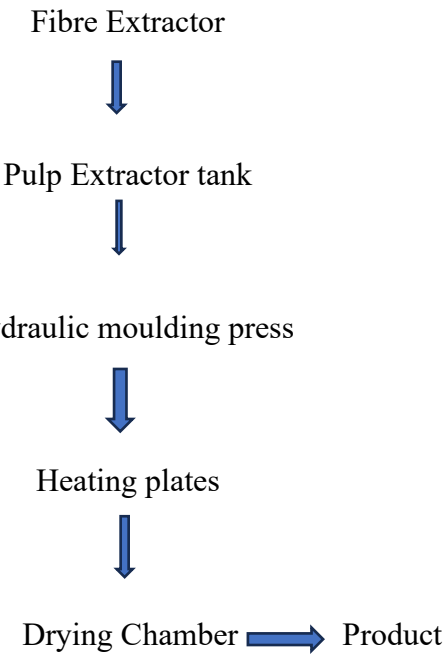
12.3 Experiment-1 An efficient extraction and processing methodology for converting banana stem waste into high-quality fiber suitable for biodegradable packaging applications.

Developing an effective extraction and processing procedure for turning banana stem waste into premium fiber appropriate for biodegradable packaging applications is the aim of this investigation. The findings show that the yield, purity, and physical characteristics of the resulting fibers are greatly impacted by the extraction method used. Fibers will be successfully separate from the banana pseudostem matrix using mechanical or chemical extraction techniques, which also enhanced the removal of lignin, hemicellulose, and

other non-cellulosic components. As a result, the fiber quality will be improved, as seen by higher cellulose content, better fibrillation, and improved surface morphology. By upsetting the binding elements, chemical treatments like alkali treatment increased the homogeneity of the fiber and enhanced its cleanliness and elasticity. Preparation of packaging product in the flow chart given below:



Machine Working Process :



12.4 Experiment-2 A biodegradable packaging system utilizing banana stem fibres

(A) Independent parameters

12.4.1 Experimental details

Parameters		Coded variables		
Fibre content	A	50%	55%	60%
Temperature (℃)	B	100 ºC	150 ºC	220 ºC
Pressure (kPa)	C	3.0 MPa	4.0 MPa	5 MPa

Std	Run	Uncoded variables		
		A: Fibre Content	B: Temperature (°C)	C: Pressure (MPa)
16	1	55	150	4
5	2	50	150	3
4	3	60	200	4
17	4	55	150	4
10	5	55	200	3
11	6	55	100	5
12	7	55	200	5
8	8	60	150	5
9	9	55	100	3
3	10	50	200	4
15	11	55	150	4
14	12	55	150	4
6	13	60	150	3
7	14	50	150	5
2	15	60	100	4
13	16	55	150	4
1	17	50	100	4
16	1	55	150	4
5	2	50	150	3

12.5 Experiment-3 Optimization process parameters to Enhance the Strength of the Developed Packaging Material

i.	Treatment Details		
	First factor	:	Fibre content
			A_1= 50%
			A_2= 55%
			A_3= 60%
	Second factor	:	Temperature
			B_1= 100 ºC
			B_2= 150 ºC
			B_3= 200 ºC
	Third factor	:	Pressure
			C_1= 3.0 MPa
			C_2= 4.0 MPa
			C_3= 5.0 MPa
ii.	Experimental design		
	(A) Independent parameters	:	i. Fibre content ii. Temperature iii. Pressure
	(B) Dependent parameters	:	i. Tensile strength ii. Elongation iii. Water absorption index iv. Density v. Hardness
iii.	Statistical design	:	Box-Behnken design (BBD)
iv.	Number of treatments	:	17

12.7 Experiment-4 evaluate the Storage Performance of the Biodegradable Developed Packaging.

Step-1 Fruit Selection (Tomato/Sapota)

A. Same Size
B. Same Maturity

Total Combination= 2 Packaging X 2 Condition X 3 Replication =12

Step-2 Packaging Type

1. Developed Biodegradable Packaging
2. Plastic (Control)

Step-3 Storage Condition

1. Ambient Condition

2. Refrigerated Condition

Step-4 Storage Duration upto 15 Days or until Spoilage of fruits (3 Days Intervals)

Step-5 Parameter Observe during Storage

1. Weight loss
2. Firmness
3. TSS
4. P^H
5. Acidity
6. Colour Change
7. Microbial Analysis

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Signature of Student **(Satyam Kumar)** **Reg. No.: 1050225008**	**Signature of Guide** **(Dr. M.N. Dabhi)**